PCT/GB 2004 / 0 0 4 1 3 6

The Patent Office

PATENTS • DESIGNS • COPYRIGHT • TRADE MARKS

REC'D 11 NOV 2004

WIPO PCT

INVESTOR IN PEOPLE

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Signed AHBrewer

Dated 3 November 2004

BEST AVAILABLE COPY

26SEP03 E840307-1 C47904
P01/7700 0.00-0322590.1

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
JL
26 SEP 2003
RECEIVED BY FAX

The Patent Office

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office
Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference — X444

2. Patent application number *(The Patent Office will fill in this part)* — 26 SEP 2003 — 0322590.1

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — Xaar Technology Limited, Science Park, Cambridge, CB4 0XR

   Patents ADP number *(if you know it)* — 07301872003

   If the applicant is a corporate body, give the country/state of its incorporation — UK

4. Title of the invention — Droplet Deposition Apparatus

5. Name of your agent *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — ~~Xaar Technology Limited, Science Park, Cambridge, CB4 0XR~~ Mathys & Squire 100 Gray's Inn Rd London WC1X 8AL

   Patents ADP number *(if you know it)* — 00001081001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* — YES
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

0081092 26-Sep-03 02:51

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	—
Description	9
Claim *(s)*	2
Abstract	—
Drawing *(s)*	10 only.

10. If you are also filing any of the following, state how many against each item.

Priority documents	—
Translations of priority documents	—
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	—
Request for preliminary examination and search *(Patents Form 9/77)*	—
Request for substantive examination *(Patents Form 10/77)*	—
Any other documents *(please specify)*	—

11. I/We request the grant of a patent on the basis of this application.

Signature Nick Roberts Date 26/9/03

12. Name and daytime telephone number of person to contact in the United Kingdom — Nick Roberts 01223 423 663

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.

d) If you have answered 'Yes' Patents Form 7/77 will need to be filed.

e) Once you have filled in the form you must remember to sign and date it.

f) For details of the fee and ways to pay please contact the Patent Office.

0081092 26-Sep-03 02:51

DUPLICATE

S

Droplet Deposition Apparatus

The present invention relates to print heads and in particular drop on demand ink jet print heads.

In industrial printing applications the throughput capability is often the key requirement. For inkjet printing the task to maximize the printed area per unit time can be addressed in different ways. A figure of merit for throughput capability of all these approaches is the total ink volume delivered by an individual nozzle in unit time.

It is an object of the present invention to seek to provide a print head construction that is capable of printing droplets of an appropriate volume at a high frequency.

According to one aspect of the present invention there is provided a droplet deposition apparatus comprising an actuator plate comprising a plurality of channels at a predetermined channel spacing, each of said channels having a predetermined length d1 a portion of said length having a constant depth and a portion of said length having a changing depth; a cover plate comprising a plurality of channels at a predetermined channel spacing and having a channel length d2, where d2 is less than d1; at least one of said actuator channels being in registry with at least one of said cover channels; a nozzle plate providing an end wall of said actuator channels and said cover channels; wherein at least some of said actuator channels comprising acoustic reflection modifying means such that the acoustic reflection of an ejection channel formed of an actuator channel in registry with a cover channel is substantially identical to the acoustic reflection of an ejection channel formed of an actuator channel which is not in registry with a cover channel.

The cover may be a piezoelectric ceramic or a material with a coefficient of thermal expansion similar to that of piezoelectric ceramic.

The end of the cover channel remote from the nozzle plate may be a plane extending orthogonal to the direction of elongation of the channel.

The acoustic reflection modifying means may comprise a groove extending transverse to the length of the actuator channels. The groove may be filled with an ejection fluid or an acoustically transparent solid.

The acoustically transparent solid may be an adhesive material such as an epoxy.

The cover channel may have a different cross-sectional area than the actuator channel. The cover channel may have a greater height to the actuator channel. The offset ejection channels formed of both cover channel and actuator channel may be formed of a height of cover channel and height of actuator channel which provide a substantially constant ejection characteristic for each channel in the array. The heights of the cover channel and actuator channel may vary for adjacent ejection channels.

The present invention will now be described, by way of example only, with reference to the following diagrams in which:

Figure 1 is an actuator according to the prior art.
Figure 2 depicts an actuator providing offset channels.
Figure 3 is a graph of resonant frequency vs misalignment of cover channels and actuator channels.
Figure 4 depicts operation of the actuator of Figure 2
Figure 5 is a graph detailing the velocity ejected from the ejection channels.
Figure 6 is a graph detailing the velocity of an ink droplet at a constant channel

depth but with Dc and Db varying.

Figure 7a and b depict drop volume vs print head frequency for two different channel depths.

Figures 8a and b are graphs showing drop velocity for different channel dimensions.

Figure 1 is a schematic of an XJ126 print head commercially available from Xaar. The print head has126 ink channels 2 capable of delivering 80 pl ink drop volume through a nozzle 4 at a maximum print frequency of 5.2 kHz. The ink channels are of 75µm width and 380µm depth and are separated by walls of 62µm thickness. The channel density is 185dpi. A nozzle plate 16 closes the front edge of the channel 12 and includes an array of nozzles 4, one nozzle for each channel.

The channel walls are formed of a piezoelectric material, PZT sawn into an actuator plate 6. The cover plate 8 is formed of a material that is passive and non-polarized. Electrodes 10 are deposited half way down both sides of the channel walls 12 and, when a field is applied between the electrodes effect deformation of the walls in Shear Mode.

The cover plate comprises an ink port 14 through which ink is supplied to the ejection channels.

With an appropriate voltage waveform applied to the channel walls on both sides of an ink channel, the induced wall motions create acoustic waves inside this ink channel, which lead to the formation of an ink drop at the nozzle plate. The nozzle plate at the front end of the XJ126-200dpi printhead contains

nozzles of 50µm diameter. Since neighbouring ink channels share a channel wall, they cannot eject drops at the very same time. It is necessary to operate the print head in 3 cycles with adjacent channels designated as A, B or C channels, all firing with the same printing frequency, but sequentially. Further details on Xaar's printheads are described in the prior art and consequentially will not be described in more detail here.

To increase the printing frequency the channel walls may be stiffened and this stiffening increases the channel wall's resonance frequency. The applicant has found that a beneficial embodiment improves the stiffness by offsetting the channels and extending the channels into the cover component. Each channel had the same depth – 450 µm – but for alternate channels the depth the channels extended into the cover Dc and actuator plate Db varied. Figure 2 depicts such an actuator.

The height of the movable channel wall is kept small to yield the desired stiffness while maintaining a large channel cross section which allows ink drops of an appropriate volume to be formed.

The cover component and the actuator component were joined after the channels were formed in each component. The walls in the cover component and the walls in the actuator component were aligned during bonding. Figure 3 is a graph depicting the frequency response of a channel wall against a misalignment in the join between the cover plate channels and the actuator plate channels. At the extremities of the graph the misalignment is +/- 30µm and the frequency of the wall is significantly reduced. There is a range of misalignment, however, within which the frequency is substantially constant regardless of the misalignment. The alignment of the walls to each other should preferably be to within +/- 6µm.

Electrodes are formed on the walls of the actuator plate using a directional

vacuum deposition process. As depicted in figure 2 this results in a coating which extends over different sections of the ejection channel depending on the depth of the channel formed in the actuator plate. Where a greater depth of channel is provided by the actuator channel then the electrode extend over a central portion of the channel. Where a smaller depth of the channel is provided by the channel in the actuator plate then the plating extends to the base of the channel.

Upon application of an electric field across each wall the walls deflect as depicted in Figure 4a and b. It was necessary to invert the polarity of the file depending on which of the channels are to be fired.

Upon operation of the actuator of Figure 2 and where Db = Dc i.e. the depth of each of the channels was 450µm with alternate channels extending 300µm into the actuator component and 150µm into the cover component and 300µm into the cover component and 150µm into the actuator component respectively, it was found that the velocity of droplets varied significantly depending which channel ejected it. A graph depicting the results is found in Figure 5.

Without wishing to be bound to this theory, the applicant believes that the higher efficiency of the upper channel is caused, in part, by a greater acoustic reflection coefficient at the end of the cover channel. The end of the cover channel terminates with a straight edge opening into an ink supply manifold this provides an efficient acoustic boundary.

As explained in the prior art, an acoustic wave is initiated in the ejection channel upon movement of the actuator walls. The wave travels rearwardly along the channel and is reflected at an acoustic boundary at a time that is a function of the speed of sound in the ink. The acoustic wave then travels forwardly along the channel – and may be reinforced by further movement of the actuator walls – and a droplet is ejected at an appropriate timing.

An acoustic boundary is provided wherever there is a change in acoustic impedance for example a change in ink depth or a sudden opening of a high impedance channel into a low impedance chamber. Other forms of acoustic boundary are well known in the prior art.

It is believed that the straight edge, orthogonal to the direction of channel length, of the end of the cover channel reflects the acoustic wave more efficiently than the acoustic boundary provided by the actuator channels.

A number of print heads were formed which had an overall channel depth of 550µm but with varying depth of cover and actuator channels. From Figure 6 it may be observed that, surprisingly, the velocity of the ink drop ejected from channels which extend a greater distance into the cover component and channels which extend a greater distance into the actuator component may be equalised by choosing appropriate depths and thereby appropriate cross-sectional areas of channels. In this embodiment, the velocity may be equalised at around 7.5m/s where the 550µm channel length is formed by 215µm and 335µm in the cover component and actuator component and respectively with alternate channels extending 335µm and 215µm in the cover component and actuator component and respectively.

It will be understood that there is an optimum channel configuration for other depths and widths of channels.

A further benefit of the offset channels is that a high frequency can be maintained yet the problems of starvation, i.e. where ink is ejected from the ejection channel at such a rate that the supply of ink to the ejection channel is interrupted, can be reduced through the provision of an ejection channel of a greater cross-sectional area.

S

Figure 7 depicts the case where an actuator is driven with a constant voltage and cycle period kept constant at 35.2 µs. Each channel configuration was driven with that voltage needed to provide a drop velocity of 6 m/s at 2 kHz printing frequency. Both, the smallest upper and lower channels with depth of DC = DB = 200µm, Figure 7a, suffered from strong starvation, showing an essentially identical decrease of the ink drop volume from 75 pl at 2 kHz to 55 pl at 9 kHz printing frequency. With increasing depth DC and DB the starvation readily reduced, and for the offset channels with largest depth DC = DB = 400µm, Figure 7b, no starvation was observed up to a printing frequency of 9 kHz.

FIGURE 8 a and b show the improvement the offset channels can achieve in overcoming a second drop slow problem. In some actuators constructions the first drop and second drops fired from a channel in a greyscale packet are ejected at very different velocities. This feature is known as "second drop slow". Increasing the channel dimensions overcome the problem but at the expense of the firing frequency as the walls are then at a lower stiffness and cannot achieve the high resonance. A typical velocity profile is as shown in figure 8a.

It has been found that by offsetting the channels a high frequency may be maintained yet the channel dimensions can be appropriately high to avoid slowing the second drop. A channel where Dc is 450µm provides droplets with velocities shown in Figure 8b.

The offset-channel printheads with monolithic cantilever design require a higher driving voltage for the lower channels than a chevron offset channel print head as depicted in Figure 9. The actuator component 6 is formed by two laminated plates pf PZT 20,22.

The glue joint between the two oppositely poled PZT materials was positioned at the center of the movable parts of the channel walls, and the movable parts of

the channel walls being fully covered with electrodes. Measurements revealed that a Chevron design compared with a monolithic design of identical offset-channel depth yielded highly increased efficiency in drop formation, and allowed to reduce the driving voltage by more than 10 V.

It has now been found that it is possible to increase the ejection characteristics further by modifying the acoustic reflection coefficient of the actuator channels. Figure 10 depicts the situation where an acoustic reflection chamber 25 is formed in the actuator component.

Figure 11 depicts the situation where the acoustic reflection chamber is formed by an acoustically transparent glue layer 30 extending a distance between 10μm and 1000μm along the length of the channel, the distance may be selected by routine experimentation to achieve the required acoustic reflection.

The actuator plate is manufactured according to the steps depicted in Figure 12. A support 30 of a material thermally matched to that of the active PZT 32 is provided with a flat portion 34 onto which the PZT or laminate PZT is mounted. The PZT is glued to the support by glue 36 that is acoustically transparent to the ink that will be used in the actuator. By acoustically transparent it is meant that a body of glue provides the same acoustic reflection coefficient as a body of ink. The glue should be chemically inert with the ink. The depth of glue between the rear of the PZT and the support is preferably greater than the depth of glue between the base of the PZT and the support as this provides a stiff join to the support yet a high acoustic reflection coefficient.

An appropriate thickness of glue at the rear of the PZT actuator provides the required acoustic reflection coefficient. Channels 38 are sawn which extend through the PZT and the glue and into the support. Epoxy glues are particularly appropriate.

The velocities of ink droplets between the upper channels (greater extension of the channel into the cover component) and the lower channels ((greater extension of the channel into the actuator component) may be equalised by applying what may be known as a 2-cycle, 2-phase firing sequence. The adjacent upper channels are actuated in the first cycle and first phase of the actuation sequence at a first voltage. The lower channels are actuated in the second phase and second cycle of the print head at the greater voltage that is required to ensure an equality in the ejection characteristics of the upper and lower channels. This technique may be used even where the acoustic reflection characteristics are modified as described above.

Forming the actuator component in this way and of this structure provides all the benefits of a run-out i.e. a variable depth portion at the rear of the ejection channel in terms of manufacturability e.g. dicing and sawing and electrical connection with an improvement in the acoustic reflection coefficient.

The actuator has been described with reference to off-set channels however, the modifications relating to an improved acoustic boundary in the actuator channels may equally apply to channels not having an offset e.g. in Figure 13, where the cover component does not have channels and Figure 14, where the cover component is provided with channels.

Channels provided in the cover provide a greater efficiency and reduced crosstalk over channels formed solely in the actuator component.

Each feature described in the specification or claims may be combined with any other feature or features described in the specification or claims without departing from the invention described herein.

Claims

1. Droplet deposition apparatus comprising
an actuator plate comprising a plurality of channels at a predetermined channel spacing, each of said channels having a predetermined length d1 a portion of said length having a constant depth and a portion of said length having a changing depth;
a nozzle plate providing an end wall of said actuator channels and said cover channels;
wherein said actuator channels comprise acoustic reflection modifying means.

2. Droplet deposition apparatus comprising
an actuator plate comprising a plurality of channels at a predetermined channel spacing, each of said channels having a predetermined length d1 a portion of said length having a constant depth and a portion of said length having a changing depth;
a cover plate comprising a plurality of channels at a predetermined channel spacing and having a channel length d2, where d2 is less than d1;
at least one of said actuator channels being in registry with at least one of said cover channels;
a nozzle plate providing an end wall of said actuator channels and said cover channels;
wherein at least some of said actuator channels comprise acoustic reflection modifying means such that the acoustic reflection of an ejection channel formed of an actuator channel in registry with a cover channel is substantially identical to the acoustic reflection of an ejection channel formed of an actuator channel which is not in registry with a cover channel.

3. Apparatus according to Claim 1 or Claim 2, wherein the acoustic reflection modifying means comprise a groove extending transverse to the length of the actuator channels.

S

4. Apparatus according to Claim 3, wherein the transverse groove is filled with an ejection fluid.

5. Apparatus according to Claim 3, wherein the transverse groove is filled with an acoustically transparent solid.

6. Apparatus according to Claim 3, wherein the acoustically transparent solid is an adhesive material.

7. Apparatus according to Claim 6, wherein the adhesive material is an epoxy.

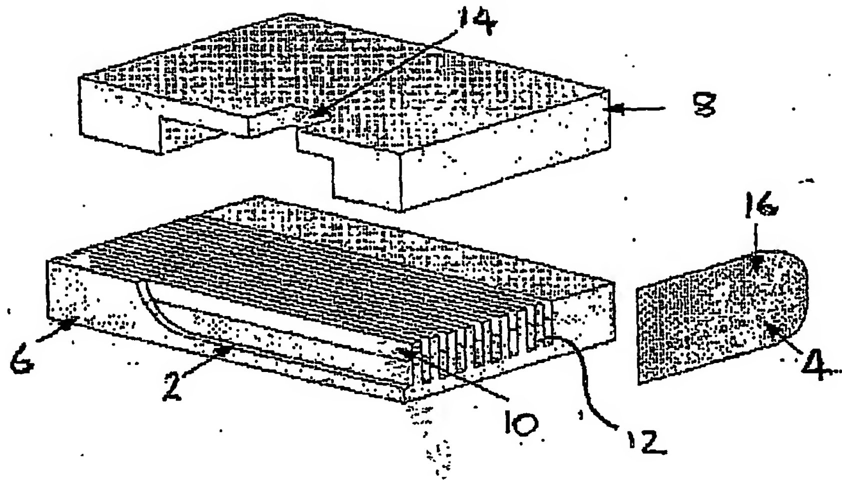

Figure 1

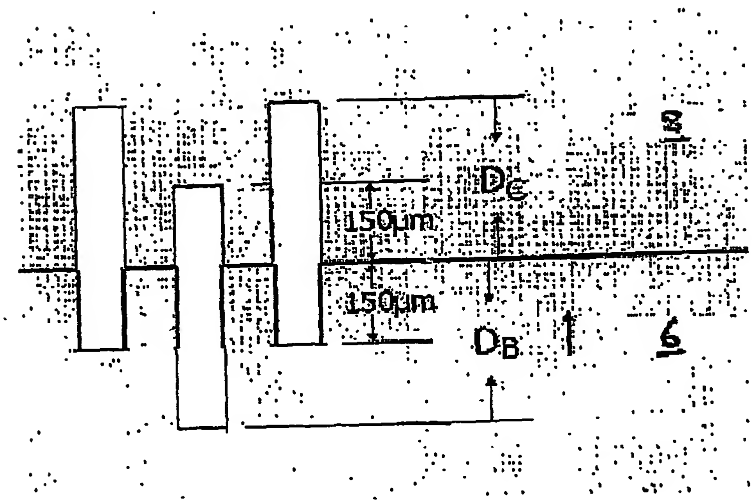

Figure 2

2/10

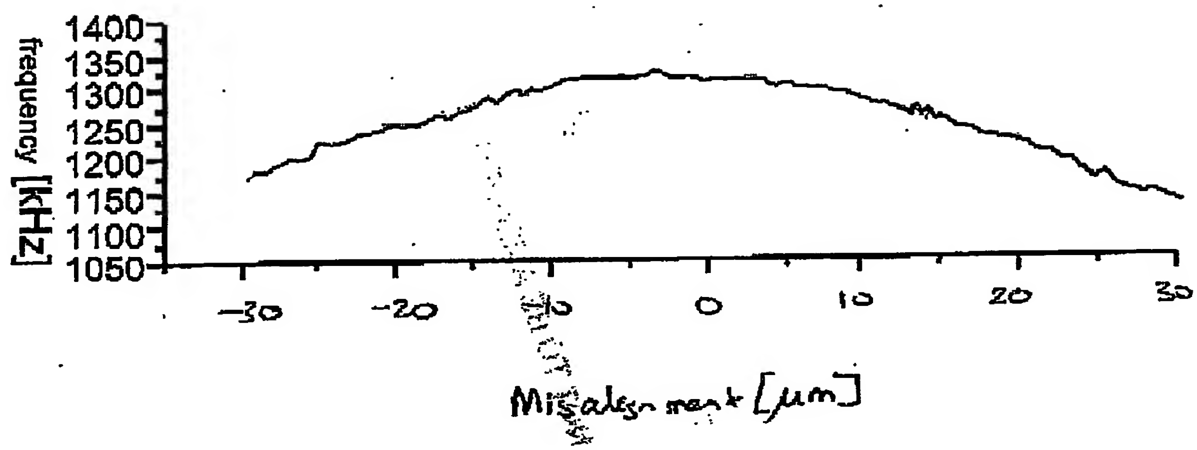
1400
1350
1300
1250
1200
1150
1100
1050
frequency [kHz]
-30
-20
-10
0
10
20
30
Misalignment [μm]

Figure 3

3/10

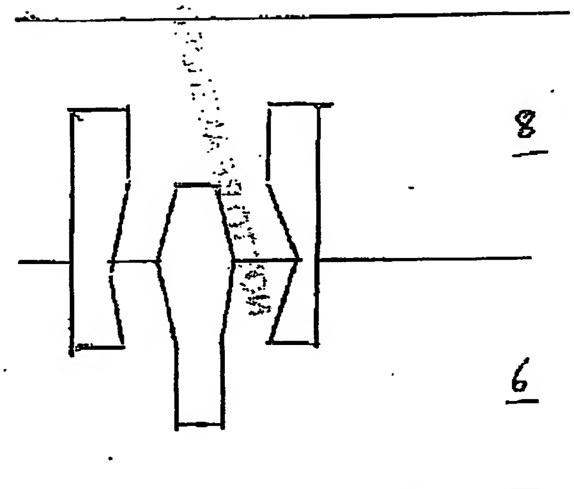

Figure 4a

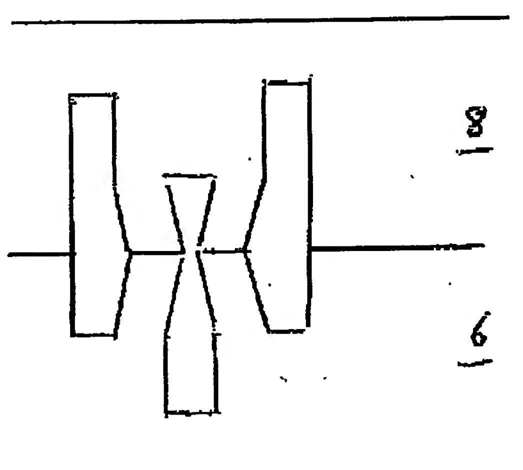

Figure 4b

4/10

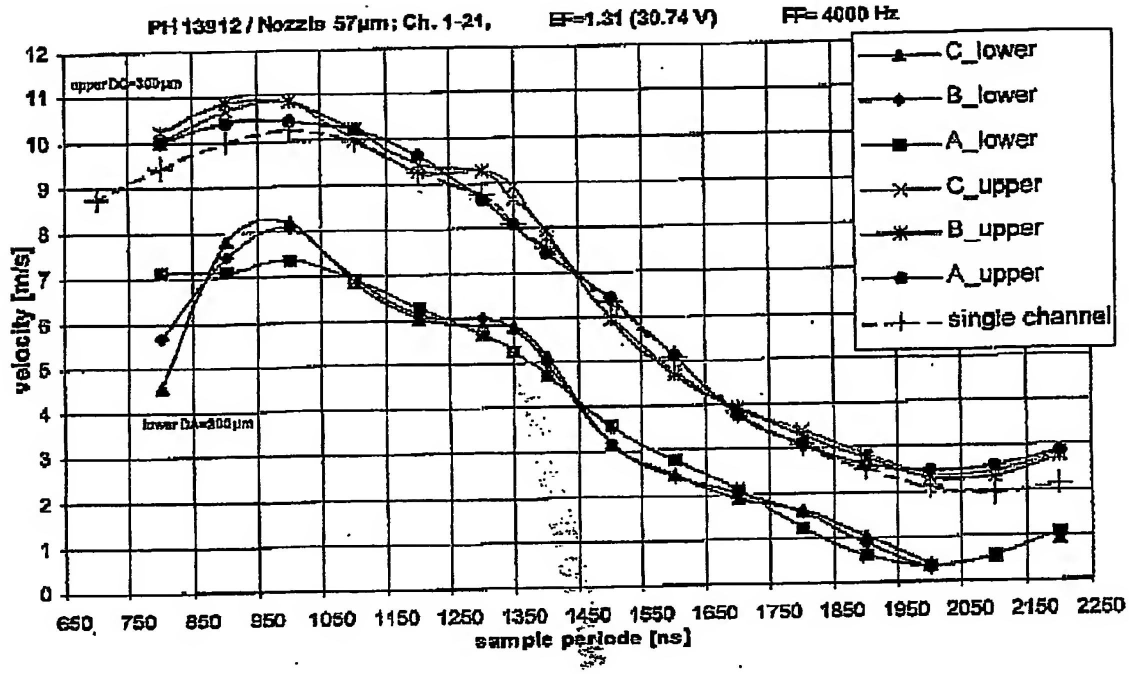

Figure 5

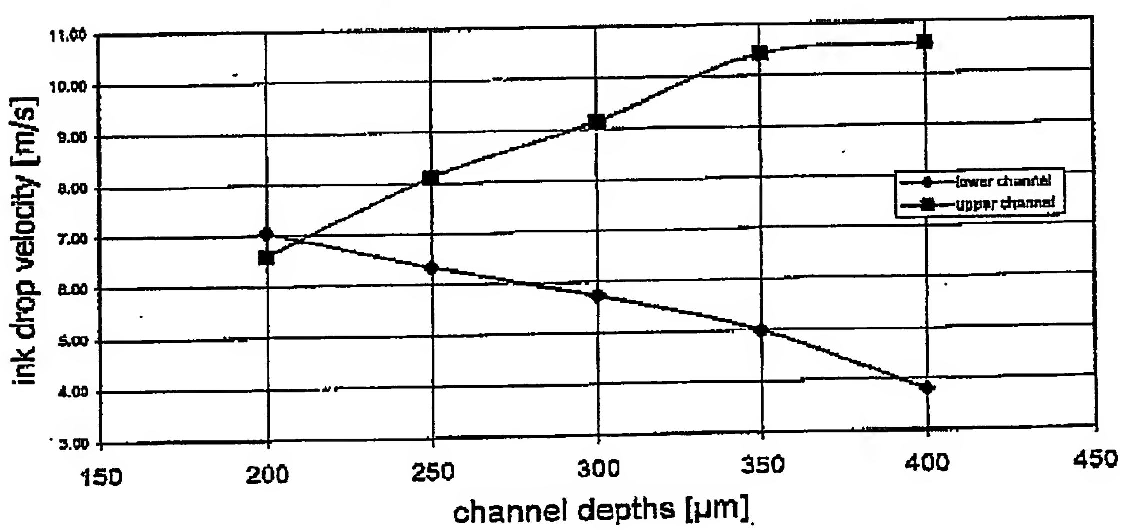

Figure 6

5/10

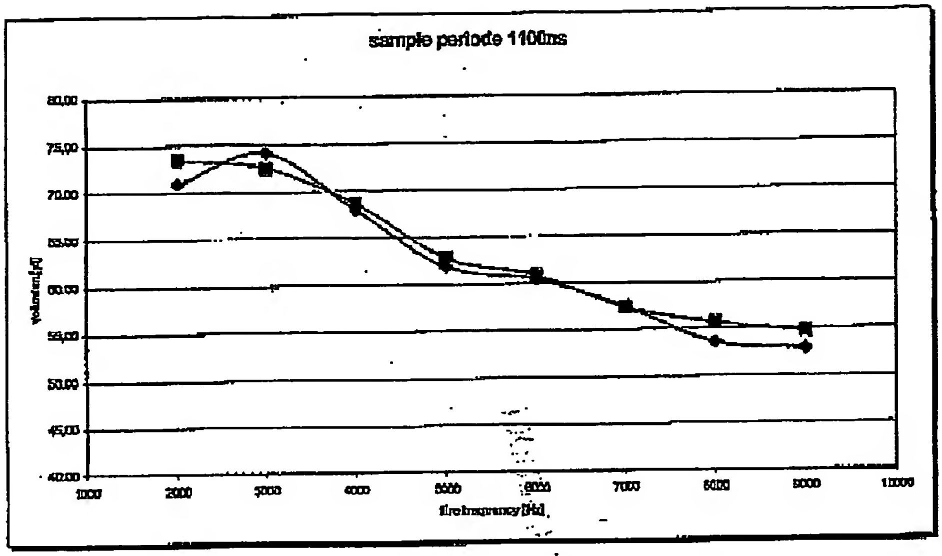

Figure 7a

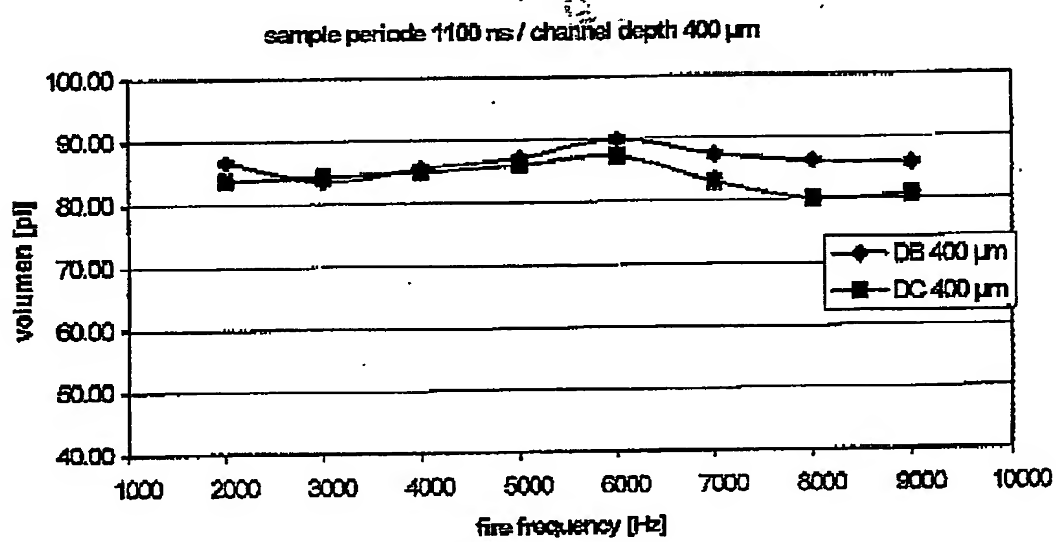

Figure 7b

6/10

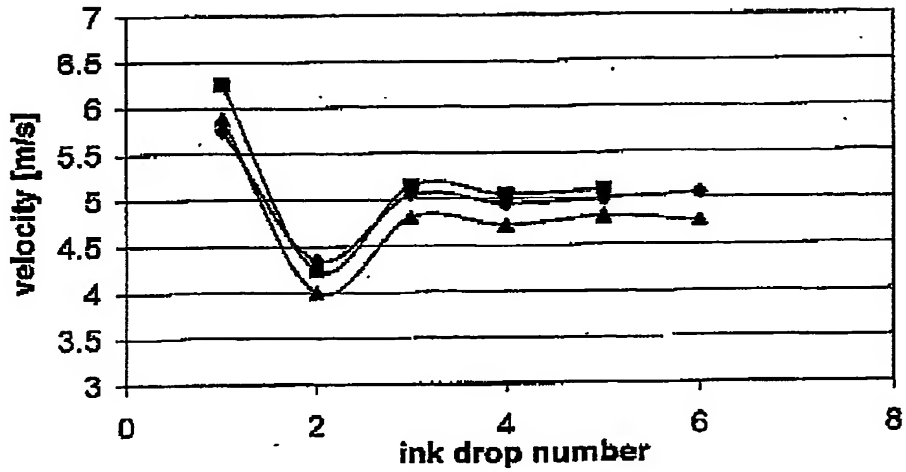

Figure 8a

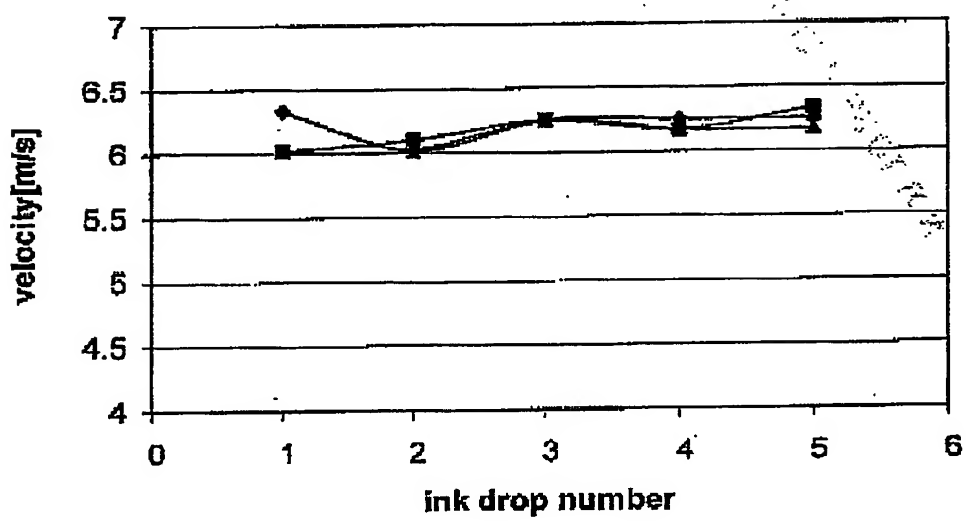

Figure 8b

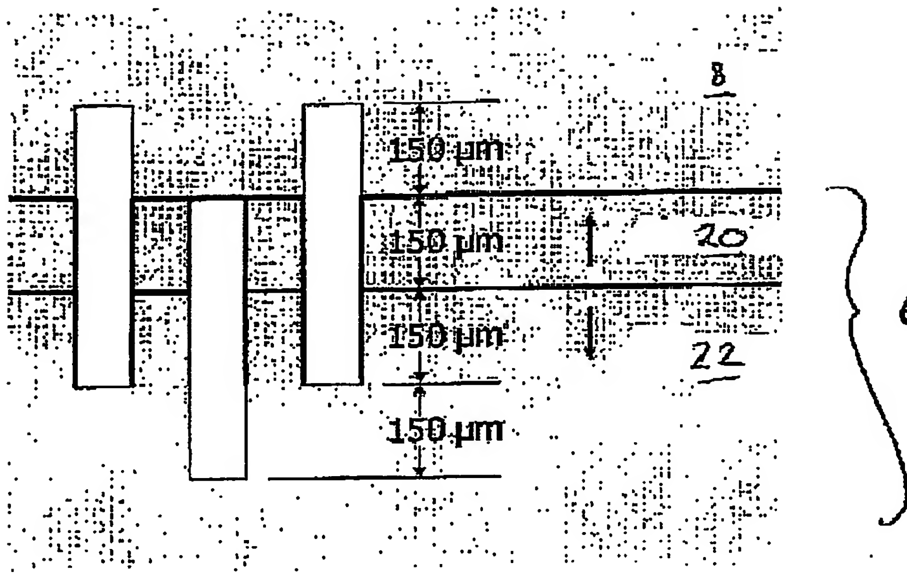

Figure 9

8/10

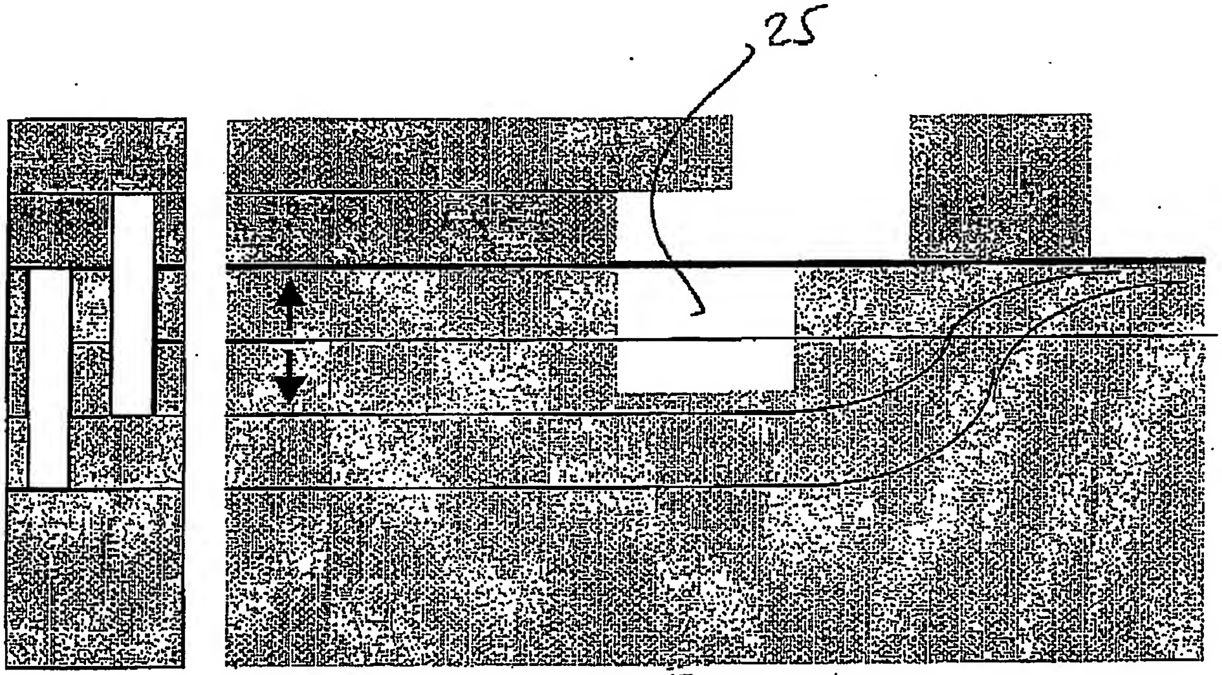

Figure 10

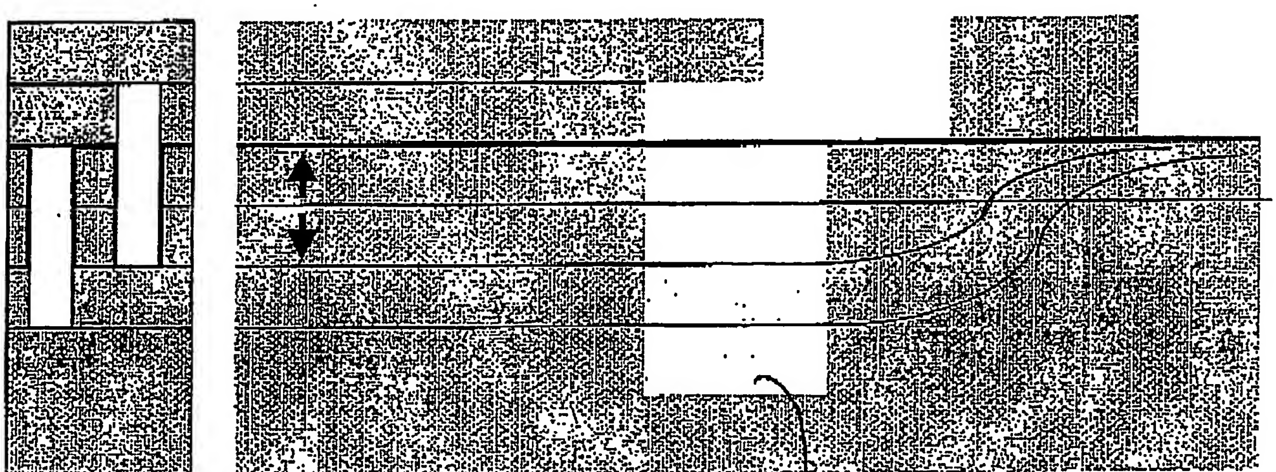

Figure 11

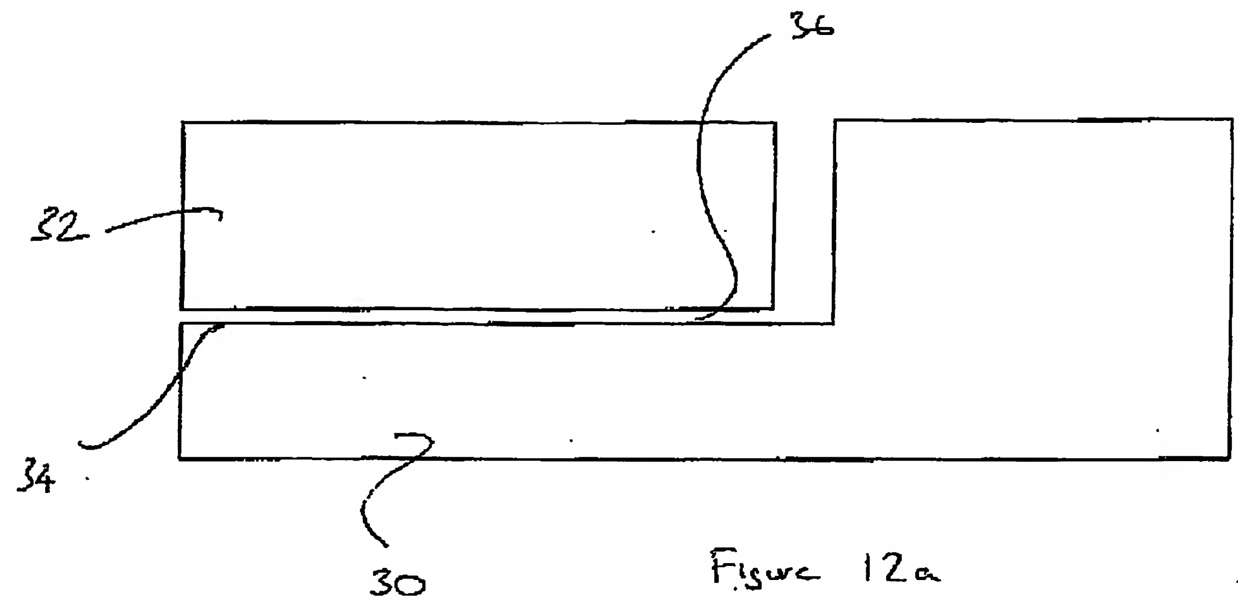

Figure 12a

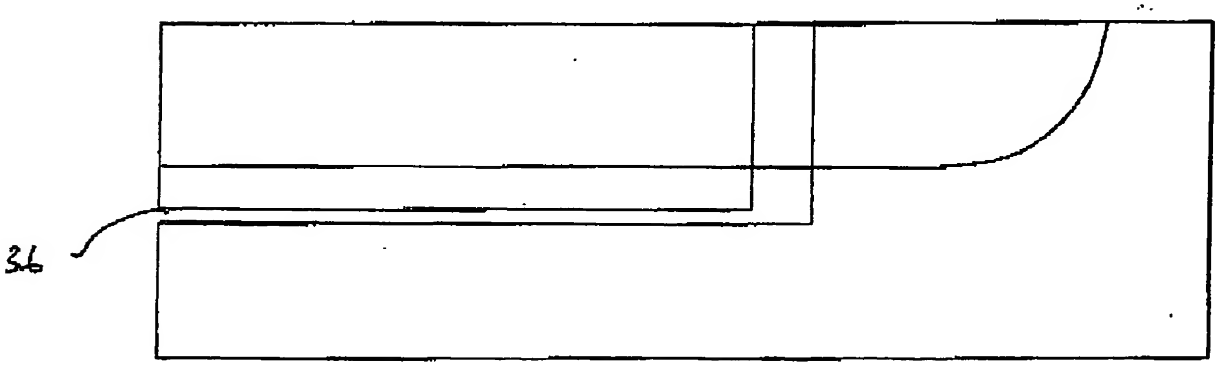

Figure 12b

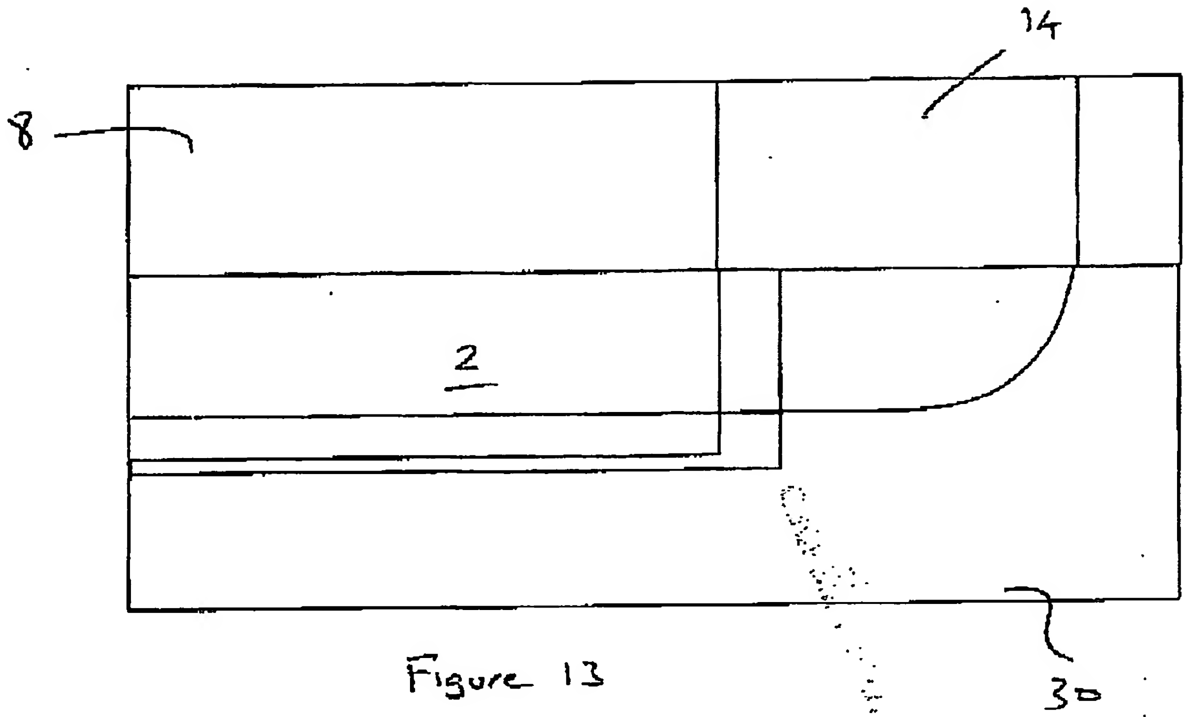

Figure 13

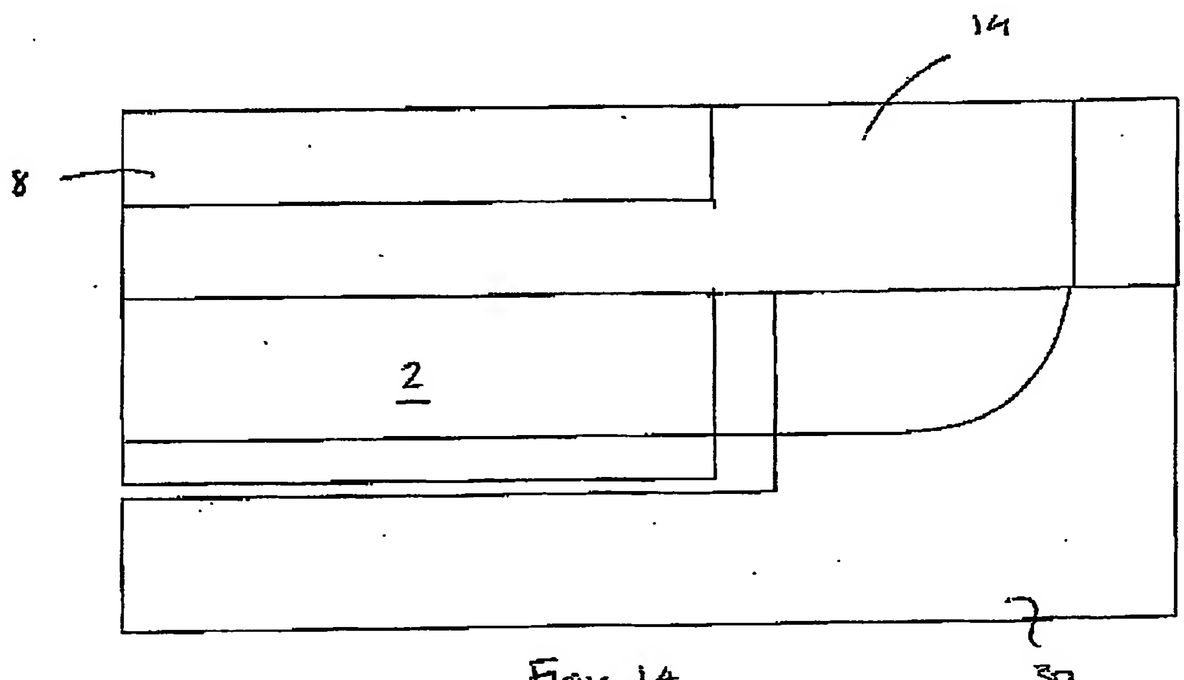

Figure 14.